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An ASABE Meeting Presentation

Paper Number: 085132

Jet Test to Evaluate the Head Cutting of Glacial Till in Auxiliary Spillways in New York State

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**Written for presentation at the
2008 ASABE Annual International Meeting
Sponsored by ASABE
Rhode Island Convention Center
Providence, Rhode Island
June 29 – July 2, 2008**

Abstract. *An evaluation of existing high hazard flood control dams built by the PL-566 Small Watershed Protection program consists of running the probable maximum precipitation through the auxiliary spillway. The Natural Resources Conservation Service uses the SITES program to model this event. Using data from the as-built drawings and the design folder estimates are made of the erosivity of the soil in the outlet section of the auxiliary spillway. If the model shows that the spillway will breach during the probable maximum precipitation event then the auxiliary spillway would need to be upgraded to current criteria to protect it from breaching. One alternative for hardening the auxiliary spillway is to install a concrete barrier across the spillway. Although the Dam Rehabilitation Program will cost share this work 65 percent, the protection of the spillways with a concrete barrier has been estimated to cost several hundred thousand dollars. Because of this high cost actual testing of the soil is recommended to evaluate the soil characteristics should be performed to verify the results of the soils data. A Jet Index test is available to provide the down cutting characteristics of soil erodibility. Soil characteristics are the excess shear stress parameters, detachment coefficient, k_d and the critical stress t_c of the actual soil in situ.*

Keywords. (Dam Rehabilitation, Erodibility, Jet Index Test, Earthen Auxiliary Spillway)

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Introduction

The Watershed Protection and Flood Prevention Act of 1954 (P.L. 83-566), as amended by the Small Watershed Rehabilitation Amendments of 2000 (PL-106-472), otherwise known as the Watershed Rehabilitation Program (PL-472). The Watershed Rehabilitation Program is administered by the Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS) to assist project sponsors with rehabilitation of aging project dams by providing technical and financial assistance to local communities to take a comprehensive approach to address local natural resource concerns. The purpose of PL-472 is to extend the service life of dams which meet applicable safety and performance standards as well as upgrading structures to meet state dam safety laws, which may include hardening auxiliary spillways to reduce the risk of breaching. Projects are eligible when hazard to life and property increases due to downstream development and when there is need for rehabilitation to extend the planned life of a structure. In the United States there have been a total of 11,307 Project dams constructed under Public Law 566 (PL 566) and Public Law 534 (PL 534). Of these 11,307 dams, there are 286 dams in the Northeast, and 59 in New York State.

NRCS developed several design manuals for the design of earthen spillways. The SCS developed Technical Paper 61, (Handbook of Channel Design for Soil and Water Conservation)⁴ which outlines the design procedures for designing channels and includes permissible velocities for bare and vegetated channels. The SITES program incorporates new earth spillway erosion technology and was made available for use in 1996, and based on this it has been upgraded to SITES 2005.1.3. The input parameters are described in further detail under the soil erodibility section of this paper.

Earthen dams in New York State are primarily homogenous embankments with concrete risers acting as the principal spillways and vegetated channels as the auxiliary spillways. Vegetated auxiliary spillways are open channels, trapezoidal in cross-section and consist of an inlet channel, a control section, and an exit channel.

The auxiliary spillway can be evaluated for headcut development and advancement during passage of the freeboard storm. In addition, the spillway design must be such that the auxiliary spillway will not breach during passage of the freeboard storm³. Breaching of the auxiliary spillway is caused by the loss of vegetative cover and subsequently the erosion of the soil below. It is important to note that the most recent rainfall data used in the breach analysis is on average 60 years of data compared to 20-30 years of data available when these dams were designed.

Soil Erodibility

The Agricultural Research Service (ARS) and NRCS developed the Earth Spillway Erosion Model² to predict the extent of erosion for a design hydrograph. The intended use of the model is to evaluate the potential for the flow to breach a spillway. This model has three phases. The first is the failure of the vegetative cover due to the detachment of particles which is due to hydraulic shear at the surface and if any, the development of concentrated flow. The second phase is the detachment of the surface due to hydraulic shear in the concentrated flow region, resulting in the formation of a headcut. The third phase is determined when erosion becomes greater than the critical flow depth, and the downward and upstream movement of the headcut is predicted. During this phase there is the potential of breaching the spillway. A headcut erodibility index, K_h , describes the resistance of the exposed soil materials to erosive attack during Phase III. Each of these phases is described in the model by a set of threshold-rate relations. The model also provides a physically based means of estimating the performance of

vegetated spillways in a flood flow. The parameters required to determine K_h are discussed below.

There are several surface parameters required as input for this model. The surface parameters are vegetative retardance, cover factor, cover maintenance, vegetative rooting depth, and representative diameter of the surface material. The model allows the user to segment the spillway into a maximum of 20 reaches. The surface parameters are used to determine the timing failure (Phase I), and the depth of flow (Phase II).

The geologic material parameters required for Phase I, Phase II, and/or Phase III include, plasticity index (PI), representative particle diameter, percent clay, bulk dry density, and the headcut erodibility index. The PI is used in determining the time of Phase I failure. The representative particle diameter (d_{75} for fine grained material) is used in the computations of the erodible particle roughness, (n_s), and in the determination of the critical stress, (τ_c), for surface detachment computations (Phases II and III). The erodible particle roughness, (n_s), is determined based on the deepest material that is exposed at the point at which a headcut develops. The percent clay and bulk dry density is used to determine the detachment coefficient, (k_d), and can be entered as an input parameter. The k_d is used in surface detachment (erosion depth) computations for Phases II and III. The headcut erodibility index, K_h is used in the determination of the headcut advance threshold and rate for Phase III³.

Generally, the following equation is used to characterize the erodibility of cohesive materials during Phase I and Phase II:

$$\varepsilon = k_d (\tau_e - \tau_c) \quad (\text{Eq. 1})$$

Where:

ε = the erosion or detachment rate in volume of soil per unit time per unit area;
 τ_e = the local effective shear stress on the erodible boundary, Pa;
 τ_c = the critical shear stress for the erodible material, Pa; and
 k_d = the erodibility or detachment coefficient.

Equation 2 is used to determine the detachment rate coefficient, k_d , within the SITES computer program based on percent clay and maximum dry density:

$$k_d = \frac{5.66 \gamma_w}{\gamma_d} \exp \left[-0.121 c_{\%}^{0.406} \left(\frac{\gamma_w}{\gamma_d} \right)^{3.1} \right] \quad (\text{Eq. 2})$$

Where:

k_d = the erodibility or detachment coefficient;
 γ_d = maximum dry density;
 γ_w = unit weight of water; and
 $C_{\%}$ = percent clay.

The NRCS has developed a Field Procedures Guide to determine the Headcut Erodibility Index (K_h)². The headcut erodibility index, K_h , represents a measure of the resistance of the soil to erosion and is used to predict spillway erosion. The K_h varies from 0.01 for noncohesive sand to values greater than 10,000 for hard rock. The concept of a headcut erodibility index is defined as:

$$K_h = M_s \times K_b \times K_d \times J_s \quad (\text{Eq. 3})$$

Where:

M_s = material strength number of soil;
 K_b = block or particle size number, which equals the ratio of RQD (Rock Quality Designation) to joint set number (J_n);
 K_d = discontinuity or interparticle bond shear strength number which equals the ratio of joint roughness number (J_r) to joint alteration number (J_a); and
 J_s = relative ground structure number.

The erodibility data required for conducting a breach analysis are as follows:

- Soil properties such as plasticity index, dry density, representative particle diameter, and percent clay of the material being eroded. It is possible to substitute the value for percent clay with the detachment rate, which may be determined by conducting Jet Index tests. The Jet Index test will be described in further detail later in this paper;
- The Headcut Erodibility Index (K_h). This value is determined by using the equations and tables found in the Field Procedures Guide for the Headcut Erodibility Index² (Eq. 3 above).

Jet Index Test

In addition to soil classification indexes, a direct method of determining the erodibility of soils has been developed. The Jet Index method is described in ASTM D5852-00(2007), Standard Test Method for Erodibility Determination of Soil in the Field or in the Laboratory by the Jet Index Method⁵.

Jet Index test data collected is then used to calculate the erodibility parameters, critical stress, and the erodibility coefficient, k_d by using a spreadsheet routine developed by Hanson and Cook (1999). The data entered in the table is used to calculate the nozzle height, J_i , time, and maximum depth of scour.

As the test progresses with time, the scour surface in the zone of the impinging jet erodes away from the jet nozzle until an equilibrium depth, J_e , is reached¹.

The erodibility coefficient, k_d is determined based on the measured scour depth, time, the pre-determined τ_c , and the dimensionless time function:

$$T^* = -J^* + 0.5 \ln \left(\frac{1+J^*}{1-J^*} \right) \Big|_{J_i^*}^{J^*} \quad (\text{Eq. 4})$$

Where:

T^* = dimensionless time, t_m/Tr ;
 t_m = measured time;
 Tr = a reference time, $J_e/(k_d \tau_c)$;
 J^* = dimensionless scour term, J/J_e ;
 J_i^* = dimensionless scour term at J_i/J_e ;
 J = the distance from the nozzle to the centerline depth of scour (m); and
 J_i = the initial distance from the nozzle to soil surface (m).

The equation has been re-written to coincide with the time measured during the Jet Index test as follows:

$$t_m = Tr \left[0.5 \ln \left(\frac{1+J^*}{1-J^*} \right) - J^* - 0.5 \ln \left(\frac{1+J_i^*}{1-J_i^*} \right) + J_i^* \right] \quad (\text{Eq. 5})$$

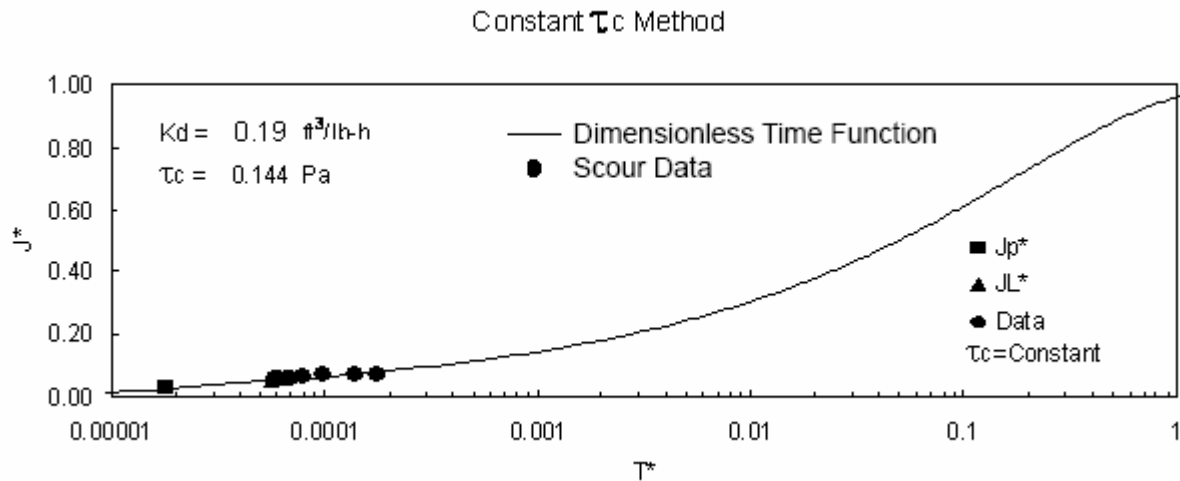


Figure 1 shows the graphical view of the dimensionless scour function:

Figure 1: k_d Plot

Field Jet Index Test Apparatus

The process for conducting the test in this study begins with selecting the site location and removing the vegetation from the area where the test will be conducted. The sites for the tests are selected by the geologist downstream of the control section along the centerline of the auxiliary spillway.

To set up the equipment, the base ring is pushed into the ground. A sledge hammer and a two by four are needed to set the base ring into the ground. The cover, jet tube and point gage are installed on the jet submergence tank. The head tank and 6' tubular steel used to support the tank is installed. This assembly is stabilized and kept vertical by connecting three ropes at the top of the tubular steel and connecting them to rebar driven into the soil. A 1.25 inch hose is then connected from the head tank to the jet tube. An additional 1.25 inch hose is connected to the jet submergence tank overflow. This hose should be long enough to carry water away from the test site. A garden hose connected to a gasoline powered pump provides water to the head tank from the water source. The water source used for these tests is a 1,000 gallon poly tank mounted on a trailer. Prior to starting the test, an initial reading is taken to measure the distance between the soil surface and nozzle. The pump is started and water is allowed to fill the head tank. A valve is opened at the head tank to allow water to fill the jet tube and the jet submergence tank. Any air trapped in the jet tube is released by opening the air relief valve.

The following photographs illustrate the typical setup used for these tests:



Photo 1: Jet Submergence Tank



Photo 2: Head Tank

Photograph one shows the typical setup of the jet tube, nozzle, point gage and jet submergence tank. Photograph 2 shows the adjustable head tank setup and connection to the jet submergence tank.

The time intervals used in this study were 30s, 30s, 60s, 120s, 120s, 300s, 600s, 1200s, 1200s, 1200s, and 1200s for a total of 6060s. Variable time intervals may be necessary depending on progress of the test over time.

Case Histories

In 2006-2007, Jet Index tests were conducted at three dam project sites in New York State. Each Jet Index test was performed at an approximate depth of one foot in order to be below the rooting depth. For these dams the breach analysis using SITES showed that in each case, the auxiliary spillways would breach based on geological information. The Jet Index test was performed to verify this result potentially saving the sponsor with the cost of hardening the spillway.

The dams evaluated in this study are classified as either Class B or Class C structures. Class B structures have a significant hazard and class C are high hazard dams with a 50 year and 100 year design life, respectively. Each of the dams has earthen auxiliary spillways. Detailed geologic investigations were conducted for all dams to analyze soil types and depth to bedrock. Several test pits (TP) and drill holes (DH) were used during the design process to evaluate the types of soils for the embankment, drainline, principal spillway, outlet channel, and the auxiliary spillways. In each case the dams need to be upgraded from significant to high hazard due to development downstream.

Case History 1

The Conewango Watershed is located in Western New York State. There are nine flood control dams within the watershed that were built under the Small Watersheds Rehabilitation Program (PL 83-566) of which three are significant and six are high hazard. Construction of these structures was completed between 1965 and 1982.

A detailed geologic investigation was conducted in 1959 on Conewango Site 13 to analyze soil types and depth to bedrock. A composite soil sample was classified as a GM material having a PI of 9, 7% clay content, maximum dry density of 118.5 pcf, representative diameter of 2.0 inches, and a head cut erodibility index, K_h of 0.065 from Equation 3 was used in SITES.

An evaluation of the breach potential was made using SITES. A k_d value of 0.42 ft³/lb-hour was used in the original SITES evaluation from the pre-existing geologic information.

For the high hazard class dam design evaluation, the results showed that the spillway started flowing at 2.9 hours and peaked at 4.6 hours. The most upstream headcut began at station 3+75 to 2+75 with a final height of 11.4 feet. The headcut having maximum final overfall began at station 5+00 to 3+22 with a final height of 12.2 feet in the SITES evaluation, the dam breached in 10.8 hours to a depth of 11.4 feet.

In June 2007, two Jet Index tests were conducted on the right auxiliary spillway. The first test was conducted in the control section at centerline. The second test was conducted 30' DS of the control section at centerline. The k_d values measured from the field tests were 0.1937 ft³/lb-hour and 0.1097 ft³/lb-hour respectively. An average k_d value of 0.1517 ft³/lb-hour was used in the SITES evaluation. Using the detachment coefficient results determined by the Jet Index test the most upstream headcut began at station 3+75 to 3+41 with a final height of 4.5 feet. The headcut having maximum final overfall height occurred at station 5+00 to station 3+66 with a final height of 12.2 feet. Based on this SITES evaluation the dam will not breach.

Case History 2

The Ischua Creek Site 2 is located near the northern edge of the Alleghany Plateau in the Town of Farmersville, Cattaraugus County, New York. There are seven flood control structures within the watershed of which one is significant and six are high hazard. Construction of these structures was completed between 1962 and 1971.

A detailed geologic investigation was conducted in 1960 to analyze soil types and depth to bedrock. The area of the west auxiliary spillway consists of primarily soil classified as a till material (GM), underlain by gravel, classified as (GP). A composite soil sample was classified as a GP, PI of 14, with 8% clay content and a maximum dry density of 131.0 pcf, representative diameter of 1.0 inches, and a head cut erodibility index, K_h of 0.03 from Equation 3 was used in SITES.

An evaluation of the breach potential was made using SITES. A k_d value of 0.16 ft³/lb-hour was used in the original SITES evaluation from the pre-existing geologic information.

For the high hazard dam evaluation, the results showed that the spillway flow started at 3.0 hours and peak at 4.5 hours. The most upstream headcut began at station 0+10 to - 0+10 with a final height of 3.9 feet. The most upstream headcut is also the headcut having maximum final overfall in the SITES evaluation, the dam breached in 7.3 hours to a depth of 3.9 feet.

In June 2007, one Jet Index test was conducted on the west auxiliary spillway. The test was conducted in the control section at centerline. The k_d value measured from the field test was 0.0848 ft³/lb-hour. Using the detachment coefficient results determined by the Jet Index test showed that the most upstream headcut began at station 0+10 to - 0+10 with a final height of 2.8 feet. The most upstream headcut is also the headcut having maximum final overfall in this SITES evaluation the dam breached in 9.4 hours to a depth of 2.8 feet.

Case History 3

The Batavia Kill Site 3 is located one mile northeast of the Village of Maplecrest, Town of Windham, Greene County, New York. There are three flood control structures within the watershed of which all three are high hazard. Construction of these structures was completed between 1971 and 1976.

A detailed geologic investigation was conducted in 1968 to analyze soil types and depth to bedrock. The area of the west auxiliary spillway consists of primarily soil classified as a lacustrine material (SM and ML). A composite soil sample was classified as a SM-ML, PI of 2, with 5% clay content and a maximum dry density of 118.0 pcf, representative diameter of 0.1887 inches, and a head cut erodibility index, K_h of 0.122 from Equation 3 was used in SITES.

An analysis of breach potential was made using SITES. A k_d value of 0.52 ft³/lb-hour was used in the original SITES evaluation from the pre-existing geologic information.

The results showed that the spillway started flow at 2.8 hours and peaked at 3.5 hours. The most upstream headcut began at station 6+00 to 5+00 with a final height of 18.1 feet. The headcut having maximum final overfall height occurred at station 9+00 to station 7+24 with a final height of 55.8 feet in this SITES evaluation the dam breached in 7.9 hours to a depth of 18.1 feet.

In July 2007, two Jet Index tests were conducted on the west auxiliary spillway. The first test was conducted in the control section at centerline. The second test was conducted 140' DS of the control section and 20 feet right of centerline. The k_d values measured from the field tests were 0.0814 ft³/lb-hour and 0.2816 ft³/lb-hour respectively. An average k_d value of 0.1815 ft³/lb-hour was used in the SITES evaluation. Using the detachment coefficient results determined by the Jet Index test showed that the most upstream headcut began at station 6+00 to 5+88 with a final height of 9.5 feet. The headcut having maximum final overfall height occurred at station 9+00 to station 7+24 with a final height of 55.8 feet in this SITES evaluation the dam did not breach.

The following tables show the dimensions of the dam and the results of a breach analysis using data from soil test pits and drill holes provided by the geologist of record.

Table 1: Watershed Flood Control Dam Physical Dimensions and results of SITES Model Study based on a k_d values

Site	Hazard Classification	Spillway Width (Ft)	Auxiliary Spillway Control Section Width (Ft)	Empirical SITES Run			Field SITES Run		
				SITES Model Study Empirical (k_d) (ft ³ /lb-hour)	Time to Breach (Hour)/ Depth of Breach (Ft)	Empirical Auxiliary Spillway Integrity	SITES Model Study Field (k_d) (ft ³ /lb-hour)	Time to Breach (Hour)/ Depth of Breach (Ft)	Field Test Auxiliary Spillway Integrity
Conewango Site 13	High	220	100	0.42	10.8/11.4	Breach	0.1517	-	No Breach
Ischua Creek Site 2	High	140	20	0.16	7.3/3.9	Breach	0.0848	9.4/2.8	Breach
Batavia Kill Site 3	High	250	50	0.52	7.9/18.1	Breach	0.1815	-	No Breach

Discussion

The purpose of conducting these tests was to validate the erodibility of the soil based on empirical relationships. Based on the test results at three different project sites for soils ranging from GC and GP (Course Gravels) to a SM-ML (Fine Sand – Silt – Clay), it was observed that the detachment coefficient (k_d) obtained from the Jet Index tests changed the overall breach analysis results in two of the three tested.

The soils for the Conewango and Ischua sites are quite similar, classified using the Unified Soil Classification System as coarse grained gravels. For the Conewango Site 13 Dam, the silty gravel (GM) material is borderline poorly graded gravel (GP). The similar (GP) material is found in the Ischua Creek Dam Site 2. Both soils have similar plasticity indexes, and clay contents. Soil materials consisting of sands and gravels, such as these, are common in western New York State. The soil material found in Batavia Kill Dam Site 3 is classified as borderline coarse grained-fine grained (SM-ML). This soil has 7% clay content similar to those soils found in the western New York dam sites.

The detachment coefficient (k_d) determined from empirical relationships verses those values determined by the Jet Index tests performed in the field are quite different. The SITES program utilizes the detachment coefficient, (k_d), equation (Eq. 2).

The following compare the detachment coefficients, (k_d), as determined by the Empirical and Field Jet Index tests used by the SITES program:

Site Name	Soil Type	PI	γ_d (lb/ft ³)	Percent Clay	Rep. Diam. (in)	Headcut Erodibility Index (K_h)	Empirical k_d (ft ³ /lb-hour)	Field k_d (ft ³ /lb-hour)
Conewango Dam Site 13	GC	9	118.5	7	2	0.065	0.42	0.1097/0.1937
Ischua Creek Dam Site 2	GP	14	131	8	1	0.03	0.16	0.0848
Batavia Kill Dam Site 3	SM-ML	2	115	7	0.1887	0.122	0.52	0.0814/0.2816

Results from using the empirical relationship of percent clay and maximum dry density and the results from the Jet Index tests determined that the two dams will not breach under design flow conditions using both Jet Index tests. The k_d results from the Jet Index tests are much less than those of the empirical relationship.

The data obtained from conducting the Jet Index tests is a result of direct measurements of soil erodibility in the field and are affected by the soil characteristics, operator and weather conditions. Since the tests are conducted at a depth of 1 foot, the water table will affect the rate and depth of scour. Operator judgment of the measured depth of scour will affect the final results as well. It is important to note that while conducting these tests, the rate of scour did not constantly decrease. Within the one to one and a half feet of homogeneous soil that these tests are conducted in, it would be anticipated that the rate would decrease steadily over time based on distance from the jet orifice to the soil interface. In fact the test results showed that the rate of scour is stepped, decreasing steadily, then increasing and finally decreasing over the time interval. The operator must be consistent in setting up the equipment and maintaining constant head pressure, since the change in pressure will affect the depth of scour. It is imperative that these tests be done carefully and in accordance with ASTM Standard D5852-00(2007) in order to be relevant.

Conclusion

The use of the Jet Index test allowed the NRCS to verify that two of these three dams will not breach in the SITES Model under design flow conditions. For the structures evaluated, rehabilitation will be much less expensive since the auxiliary spillways would not have to be hardened to prevent breaching. Additional Jet Index tests will be performed to verify the test results since there is some variation within each spillway. Also, additional tests will be performed on other dam earthen spillways that the geological data utilized by SITES indicates a breach. With the technical verification from the NRCS, the Sponsors, or Owner of the dams can now move forward with upgrading these dams to meet current Federal and State regulations either at a lower cost when the model shows no breach or with confidence in the results that the spillway breaches using both methods.

References

1. Cook, Kevin R., Hanson, G.J. 2004. "Apparatus, Test Procedures, and Analytical Methods to Measure Soil Erodibility In Situ", U.S. Department of Agriculture, Agriculture Research Service, Stillwater, OK.
2. U.S. Department of Agriculture, Natural Resources Conservation Service. 1997. "National Engineering Handbook, Part 628, Dams".
3. U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division. 2005. Technical Release 60, "Earth Dams and Reservoirs".
4. U.S. Department of Agriculture, Soil Conservation Service. 1954. "Handbook of channel design for soil and water conservation". SCS-TP-61, rev., 34 pp.
5. ASTM 2000(2007). Standard D5852. Standard Test Method for Erodibility Determination of Soil in the Field or in the Laboratory by the Jet Index Method.